3.1 — The Problem of Causal Inference

ECON 480 • Econometrics • Fall 2021

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[ryansafner/metricsF21](https://github.com/ryansafner/metricsF21)

metricsF21.classes.ryansafner.com

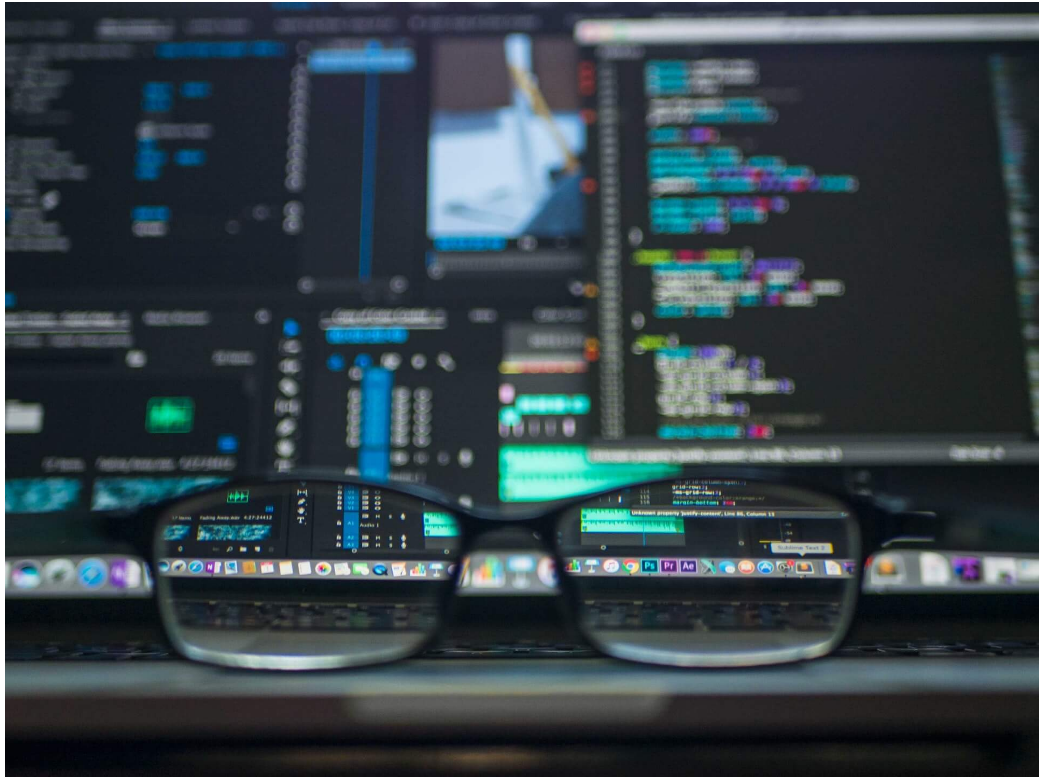
Outline

Different Uses for Statistics & Econometrics

$$Y = f(X)$$

1. **Causal inference**: how changes in X *cause* changes in Y
    - Care more about accurately estimating f than getting an accurate $\hat{Y}$
    - Measure the **causal effect** of $X \mapsto Y$ (e.g., $\hat{\beta}_1$)
2. **Prediction**: predict $\hat{Y}$ using an estimated f
    - Care more about getting $\hat{Y}$ as accurate as possible, f is an unknown "black-box"
    - **Forecasting**: predict future *values* of Y (inflation, sales, GDP)
    - **Classification**: predict the *category* of an outcome (success or failure, cat picture or not cat picture)

- We care (in this class at least) only about the first

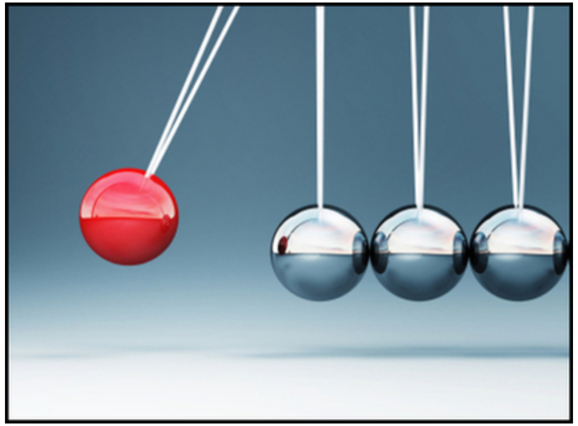


Recall: The Two Big Problems with Data

- We use econometrics to **identify** causal relationships and make **inferences** about them

1. Problem for **identification**: **endogeneity**
    - X is **exogenous** if $cor(x, u) = 0$
    - X is **endogenous** if $cor(x, u) \neq 0$

2. Problem for **inference**: **randomness**
    - Data is random due to **natural sampling variation**
    - Taking one sample of a population will yield slightly different information than another sample of the same population



The Two Problems: Identification and Inference

$$\textbf{Sample} \xrightarrow{\text{statistical inference}} \textbf{Population} \xrightarrow{\text{causal indentification}} \textbf{Unobserved Parameters}$$

The Two Problems: Identification and Inference

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- We saw how to statistically **infer** values of population parameters using our sample
  - **Purely empirical, math & statistics** 🤓

The Two Problems: Identification and Inference

$$\textbf{Sample} \xrightarrow{\text{statistical inference}} \textbf{Population} \xrightarrow{\text{causal indentification}} \textbf{Unobserved Parameters}$$

- We saw how to statistically **infer** values of population parameters using our sample
  - **Purely empirical, math & statistics** 🤓
- We now confront the problem of **identifying** causal relationships within population
  - **Endogeneity problem**
  - Even if we had perfect data on the whole population, **"Does X truly cause Y?"**, and can we measure that effect?
  - **More philosophy & theory than math & statistics!** 🧐
- Truly you should do this first, *before* you get data to make inferences!

What Does Causation Mean?

- We are going to reflect on one of the biggest problems in **epistemology**, the philosophy of knowledge

- We see that X and Y are **associated** (or quantitatively, **correlated**), but how do we know if **X *causes* Y?**

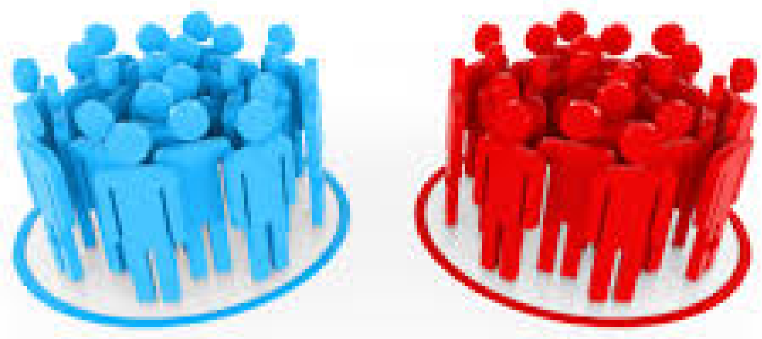
First Pass at Causation: RCTs

Random Control Trials (RCTs) I

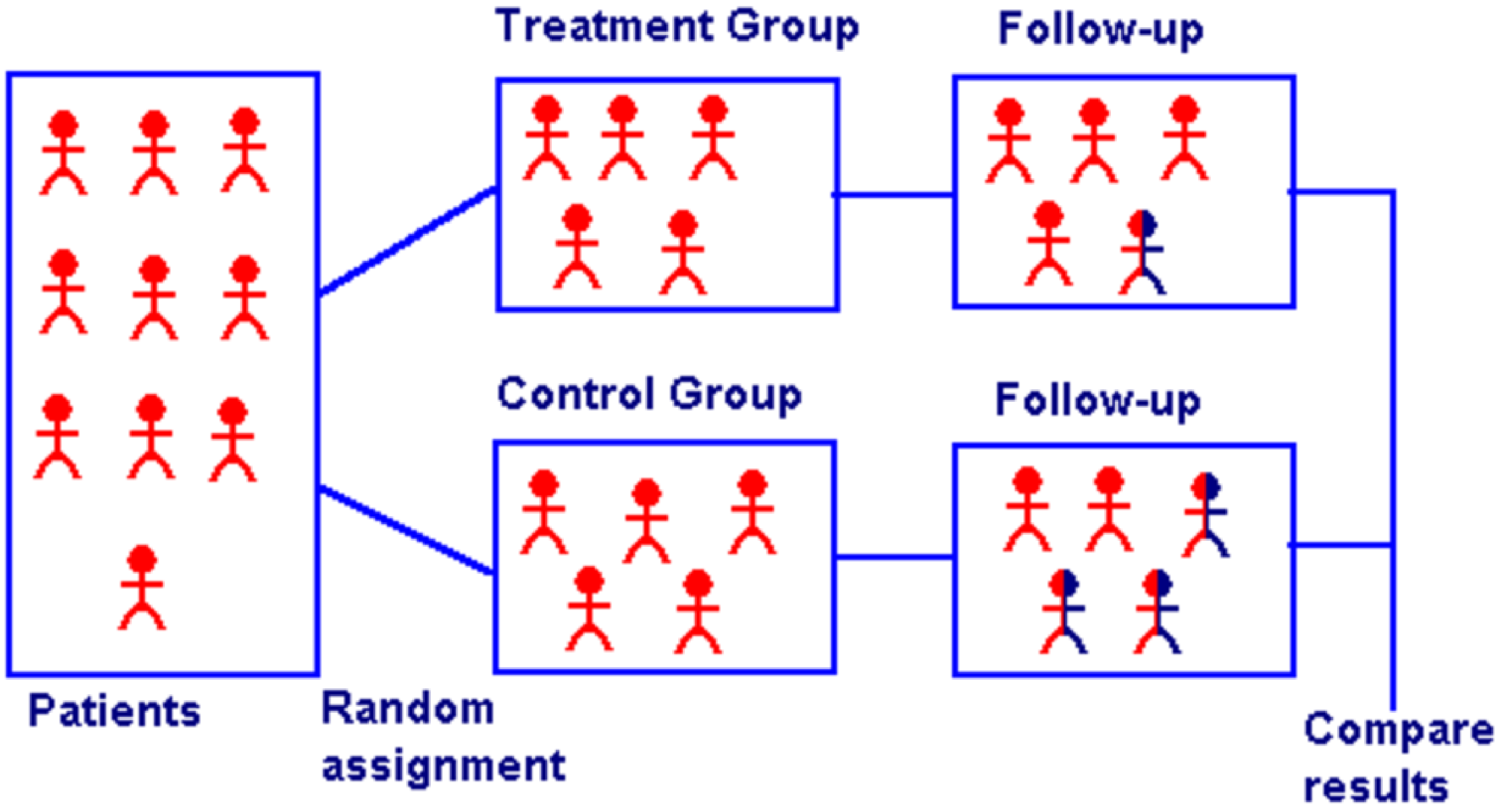
- The *ideal* way to demonstrate causation is through a **randomized control trial (RCT)** or "random experiment"

    - *Randomly* assign experimental units (e.g. people, firms, etc.) into groups
    - **Treatment group(s)** get a (kind of) treatment
    - **Control group** gets no treatment
    - Compare results of treatment and control groups to observe the **average treatment effect (ATE)**

- **We will understand “causality” (for now) to mean the ATE from an ideal RCT**



Random Control Trials (RCTs) II



Classic (simplified) procedure of a randomized control trial (RCT) from medicine

Random Control Trials (RCTs) III

Random Control Trials (RCTs) IV

- **Random assignment** to groups ensures that the *only* differences between members of the treatment(s) and control groups is *receiving treatment or not*

Treatment Group

Control Group

Random Control Trials (RCTs) IV

- **Random assignment** to groups ensures that the *only* differences between members of the treatment(s) and control groups is *receiving treatment or not*

- **Selection bias:** (pre-existing) differences between members of treatment and control groups *other* than treatment, that affect the outcome

Treatment Group

Control Group

(Selection Bias)

Potential Outcomes

The Fundamental Problem of Causal Inference

- Suppose we have some outcome variable Y

- Individuals (i) face a choice between two outcomes (such as being **treated** or **not treated**):

  - Y_i^0: outcome when individual i is **not treated**
  - Y_i^1: outcome when individual i is **treated**

$$✨ \delta_i = Y_i^1 - Y_i^0 ✨$$

- δ_i is the **causal effect** of treatment on individual i

The Fundamental Problem of Causal Inference

$$✨ \delta_i = Y_i^1 - Y_i^0 ✨$$

- This is a nice way to think about the ideal proof of causality, but this is impossible to observe!

The Fundamental Problem of Causal Inference

$$\delta_i = ? - Y_i^0$$

- This is a nice way to think about the ideal proof of causality, but this is impossible to observe!

- **Individual counterfactuals do not exist ("the path not taken")**

- You will always only ever get one of these per individual!

The Fundamental Problem of Causal Inference

$$\delta_i = Y_i^1 - ?$$

- This is a nice way to think about the ideal proof of causality, but this is impossible to observe!
- **Individual counterfactuals do not exist ("the path not taken")**
- You will always only ever get one of these per individual!
  - e.g. what would your life have been like if you did not go to Hood College?? 🧐
- So what can we do?

The Fundamental Problem of Causal Inference

$$ATE = E[Y_i^1] - E[Y_i^0]$$

- Have large groups, and take *averages* instead!
- **Average Treatment Effect (ATE)**: difference in the average (expected value) of outcome Y between treated individuals and untreated individuals

$$\delta = (\bar{Y}|D = 1) - (\bar{Y}|D = 0)$$

- D_i is a **binary variable**, $= \begin{cases} 0 & \text{if person is not treated} \\ 1 & \text{if person is treated} \end{cases}$
  - I'd much rather call this T_i, standing for Treatment, but this notation is famous

The Fundamental Problem of Causal Inference

$$ATE = E[Y_i^1] - E[Y_i^0]$$

Again:

- **Either** we observe individual i in the **treatment group** $(D = 1)$, i.e.

$$\delta_i = Y_i^1 - ?$$

- **Or** we observe individual i in the **control group** $(D = 0)$, i.e.

$$\delta_i = ? - Y_i^0$$

- **Never both** at the same time:

$$✨\ \delta_i = Y_i^1 - Y_i^0\ ✨$$

Example: The Effect of Having Health Insurance I

Example: What is the effect of having health insurance on health outcomes?

- National Health Interview Survey (NHIS) asks "Would you say your health in general is excellent, very good, good, fair, or poor?"
- **Outcome variable** (Y): Index of health (1-poor to 5-excellent) in a sample of married NHIS respondents in 2009 who may or may not have health insurance
- **Treatment** (X): Having health insurance (vs. not)

Example: The Effect of Having Health Insurance II

	Husbands			Wives		
	Some HI (1)	No HI (2)	Difference (3)	Some HI (4)	No HI (5)	Difference (6)
			A. Health			
Health index	4.01 [.93]	3.70 [1.01]	.31 (.03)	4.02 [.92]	3.62 [1.01]	.39 (.04)
			B. Characteristics			
Nonwhite	.16	.17	−.01 (.01)	.15	.17	−.02 (.01)
Age	43.98	41.26	2.71 (.29)	42.24	39.62	2.62 (.30)
Education	14.31	11.56	2.74 (.10)	14.44	11.80	2.64 (.11)
Family size	3.50	3.98	−.47 (.05)	3.49	3.93	−.43 (.05)
Employed	.92	.85	.07 (.01)	.77	.56	.21 (.02)
Family income	106,467	45,656	60,810 (1,355)	106,212	46,385	59,828 (1,406)
Sample size	8,114	1,281		8,264	1,131	

Angrist, Joshua & Jorn-Steffen Pischke, 2015, *Mostly Harmless Econometrics*

Example: The Effect of Having Health Insurance III

- Y: outcome variable (health index score, 1-5)

- Y_i: health score of an individual i

- Individual i has a choice, leading to one of two outcomes:

  - Y_i^0: individual i has *not* purchased health insurance **("Control")**
  - Y_i^1: individual i has purchased health insurance **("Treatment")**

- $\delta_i = Y_i^1 - Y_i^0$: causal effect for individual i of purchasing health insurance

Example: A Hypothetical Comparison

John	Maria
	
$Y_J^0 = 3$	$Y_M^0 = 5$
$Y_J^1 = 4$	$Y_M^1 = 5$

- John will choose to buy health insurance
- Maria will choose to not buy health insurance

Example: A Hypothetical Comparison

John	Maria
	
$Y^0_J = 3$	$Y^0_M = 5$
$Y^1_J = 4$	$Y^1_M = 5$
✨ $\delta_J = 1$	$\delta_M = 0$ ✨

- John will choose to buy health insurance
- Maria will choose to not buy health insurance
- Health insurance improves John's score by 1, has no effect on Maria's score (individual causal effects δ_i)

Example: A Hypothetical Comparison

John	Maria
	
$Y^0_J = 3$	$Y^0_M = 5$
$Y^1_J = 4$	$Y^1_M = 5$
✨ $\delta_J = 1$	$\delta_M = 0$ ✨
$Y_J = (Y^1_J) = 4$	$Y_M = (Y^0_M) = 5$

- John will choose to buy health insurance
- Maria will choose to not buy health insurance
- Health insurance improves John's score by 1, has no effect on Maria's score (individual causal effects δ_i)
- Note, all we can observe in the data are their health outcomes *after* they have chosen (not) to buy health insurance:

$$Y_J = 4$$
$$Y_M = 5$$

Example: A Hypothetical Comparison

John	Maria
	
$Y_J^0 = 3$	$Y_M^0 = 5$
$Y_J^1 = 4$	$Y_M^1 = 5$
✨ $\delta_J = 1$	$\delta_M = 0$ ✨
$Y_J = (Y_J^1) = 4$	$Y_M = (Y_M^0) = 5$

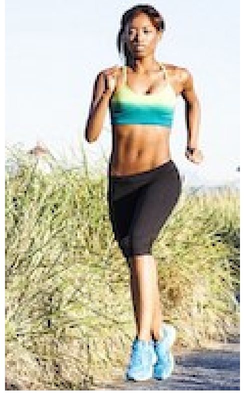
- John will choose to buy health insurance
- Maria will choose to not buy health insurance
- Health insurance improves John's score by 1, has no effect on Maria's score (individual causal effects δ_i)
- Note, all we can observe in the data are their health outcomes *after* they have chosen (not) to buy health insurance:

$$Y_J = 4$$
$$Y_M = 5$$

- ***Observed* difference** between John and Maria:

$$Y_J - Y_M = -1$$

Counterfactuals

John	Maria
	
$Y_J = 4$	$Y_M = 5$

This is all the data we *actually* observe

- Observed difference between John and Maria:

$$Y_J - Y_M = \underbrace{Y_J^1 - Y_M^0}_{=-1}$$

- Recall:
  - John has bought health insurance Y_J^1
  - Maria has not bought insurance Y_M^0
- We don't see the **counterfactuals**:
  - John's score *without* insurance
  - Maria score *with* insurance

Counterfactuals

John	Maria
	
$Y_J = 4$	$Y_M = 5$

This is all the data we *actually* observe

- Observed difference between John and Maria:

$$Y_J - Y_M = \underbrace{Y_J^1 - Y_M^0}_{=-1}$$

- Algebra trick: add and subtract Y_J^0 to equation

$$Y_j - Y_M = \underbrace{Y_J^1 - Y_J^0}_{=1} + \underbrace{Y_J^0 - Y_M^0}_{=-2}$$

- $Y_J^1 - Y_J^0 = 1$: **Causal effect for John** of buying insurance, δ_J
- $Y_J^0 - Y_M^0 = -2$: Difference between John & Maria pre-treatment, **"selection bias"**

Example II

$$Y_J^0 - Y_M^0 \neq 0$$

- **Selection bias:** (pre-existing) differences between members of treatment and control groups *other* than treatment, that affect the outcome
  - i.e. John and Maria *start out* with very *different* health scores before either decides to buy insurance or not ("recieve treatment" or not)

John (Treated)

Maria (Control)

Example II

$$Y_J^0 - Y_M^0 \neq 0$$

- The choice to get treatment is **endogenous**
- A choice made by optimizing agents
- John and Maria have different preferences, endowments, & constraints that cause them to make different decisions

John (Treated)

Maria (Control)

Example: Our Ideal Data

Ideal (but impossible) Data

Individual	Insured	Not Insured	Diff
John	4.0	3.0	1.0
Maria	5.0	5.0	0.0
Average	4.5	4.0	**0.5**

- **Individual treatment effect** (for individual i):

$$\delta_i = Y_i^1 - Y_i^0$$

- ***Average* treatment effect**:

$$ATE = \frac{1}{n}\sum_{i=1}^{n}(Y_i^1 - Y_i^0)$$

Actual (observed) Data

Individual	Insured	Not Insured	Diff
John	4.0	?	?
Maria	?	5.0	?
Average	?	?	?

- We never get to see each person's **counterfactual** state to compare and calculate ITEs or ATE
  - Maria with insurance Y_M^1
  - John without insurance Y_J^0

Can't We Just Take the Difference of Group Means?

- Can't we just take the difference in group means?

$$diff. = Avg(Y_i^1|D=1) - Avg(Y_i^0|D=0)$$

Actual (observed) Data

Individual	**Insured**	**Not Insured**	**Diff**
John	4.0	?	?
Maria	?	5.0	?
Average	?	?	?

- We never get to see each person's **counterfactual** state to compare and calculate ITEs or ATE
  - Maria with insurance Y_M^1
  - John without insurance Y_J^0

Can't We Just Take the Difference of Group Means?

- Can't we just take the difference in group means?

$$diff. = Avg(Y_i^1 | D = 1) - Avg(Y_i^0 | D = 0)$$

- Suppose there is a uniform treatment effect, δ_i

$$= Avg(Y_i^1 | D = 1) - Avg(Y_i^0 | D = 0)$$
$$= Avg(\delta_i + Y_i^0 | D = 1) - Avg(Y_i^0 | D = 0)$$
$$= \delta_i + \underbrace{Avg(Y_i^0 | D = 1) - Avg(Y_i^0 | D = 0)}_{\text{selection bias}}$$

$$= ATE + \text{selection bias}$$

Actual (observed) Data

Individual	Insured	Not Insured	Diff
John	4.0	?	?
Maria	?	5.0	?
Average	?	?	?

- We never get to see each person's **counterfactual** state to compare and calculate ITEs or ATE
  - Maria with insurance Y_M^1
  - John without insurance Y_J^0

Example: Thinking about the Data

- Basic comparisons tell us *something* about outcomes, but not **ATE**

$$diff. = ATE + \text{Selection Bias}$$

- **Selection bias**: difference in average Y_i^0 between groups pre-treatment
- Y_i^0 includes *everything* about person i relevant to health *except* treatment (insurance) status
  - Age, sex, height, weight, climate, smoker, exercise, diet, etc.
  - Imagine a world where *nobody* gets insurance (treatment), who would have highest health scores?

Actual (observed) Data

Individual	Insured	Not Insured	Diff
John	4.0	?	?
Maria	?	5.0	?
Average	?	?	?

Understanding Selection Bias

- **Treatment group** and **control group** differ on average, for reasons *other* than getting treatment or not!

- **Control group** is not a good counterfactual for **treatment group** without treatment

  - Average *untreated* outcome for the treatment group differs from average untreated outcome for *untreated* group

$$Avg(Y_i^0|D=1) - Avg(Y_i^0|D=0)$$

- Recall we cannot observe $Avg(Y_i^0|D=1)$!

John (Treated)

Maria (Control)

Understanding Selection Bias

- Consider the problem in regression form:

$$Y = \beta_0 + \beta_1 D_i + u_i$$

- Where

$$D_i = \begin{cases} 0 & \text{if person is not treated} \\ 1 & \text{if person is treated} \end{cases}$$

- The problem is $cor(D, u) \neq 0$!
  - D_i (Treatment) is endogenous!
  - *Getting* treatment is correlated with other factors that determine health!

John (Treated)

Maria (Control)

Random Assignment: The Silver Bullet

- If treatment is **randomly assigned** for a large sample, it eliminates selection bias!
- Treatment and control groups differ **on average** by nothing *except* treatment status
- Creates **ceterus paribus** conditions in economics: groups are identical **on average** (holding constant age, sex, height, etc.)

Treatment Group

Control Group

Random Assignment: The Silver Bullet

- Consider the problem in regression form:

$$Y = \beta_0 + \beta_1 D_i + u_i$$

- If treatment D_i is administered *randomly*, it breaks the correlation with u_i!
  - Treatment becomes **exogenous**
  - $cor(D, u) = 0$

Treatment Group

Control Group

Natural Experiments

The Quest for Causal Effects I

- RCTs are considered the "gold standard" for causal claims

- But society is not our laboratory (probably a good thing!)

- We can rarely conduct experiments to get data

The Quest for Causal Effects II

- Instead, we often rely on **observational data**

- This data is *not random*!

- Must take extra care in forming an **identification strategy**

- To make good claims about causation in society, we must get clever!

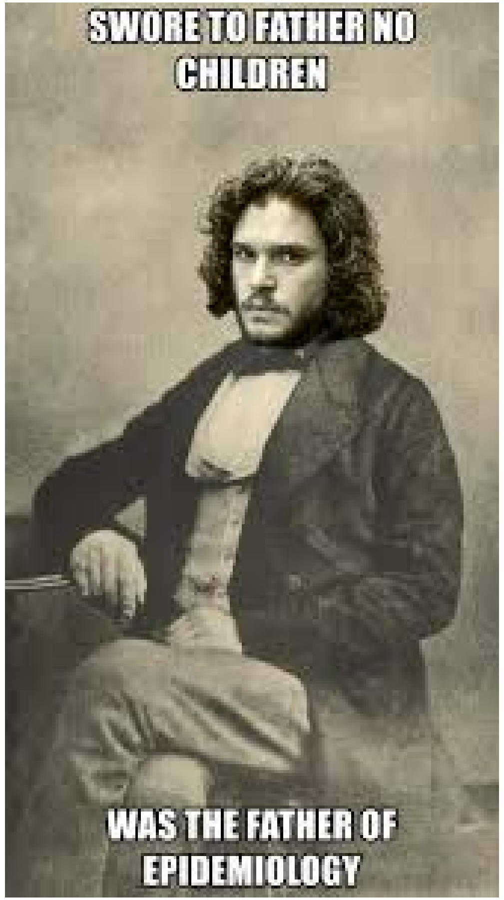
Natural Experiments

- Economists often resort to searching for **natural experiments**

- Some events beyond our control occur that separate *otherwise similar* entities into a "treatment" group and a "control" group that we can compare

- e.g. natural disasters, U.S. State laws, military draft

The First Natural Experiment

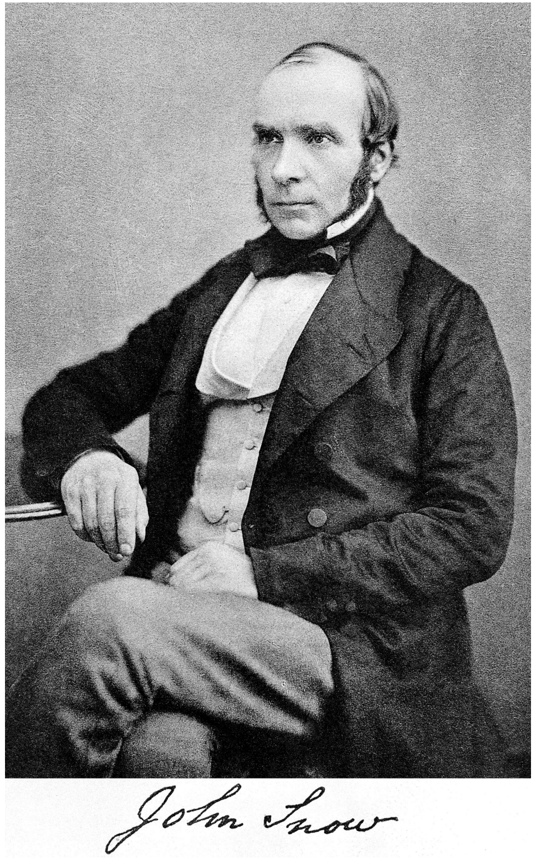


1813-1858

- John Snow utilized the first famous natural experiment to establish the foundations of epidemiology and the germ theory of disease

- Water pumps with sources *downstream* of a sewage dump in the Thames river spread cholera while water pumps with sources *upstream* did not

The First Natural Experiment



1813-1858

- John Snow utilized the [first famous natural experiment] to establish the foundations of epidemiology and the germ theory of disease

- Water pumps with sources *downstream* of a sewage dump in the Thames river spread cholera while water pumps with sources *upstream* did not

Famous Natural Experiments

- **Oregon Health Insurance Experiment**: Oregon used lottery to grant Medicare access to 10,000 people, showing access to Medicaid increased use of health services, lowered debt, etc. relative to those not on Medicaid
- **Angrist (1990)** finds that lifetime earnings of (random) drafted Vietnam veterans is 15% lower than non-veterans
- **Card & Kreuger (1994)** find that minimum wage hike in fast-food restaurants on NJ side of border had no disemployment effects relative to restaurants on PA side of border during the same period
- **Acemoglu, Johnson, and Robinson (2001)** find that inclusive institutions lead to higher economic development than extractive institutions, determined by a colony's disease environment in 1500
- We will look at some of these in greater detail throughout the course
- A great list, with explanations is here

Attack of/on the Randomistas

Google

rct "gold standard"

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JOG. Author manuscript; available in PMC 2018 Dec 1.
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NIHMSID: NIHMS966617
PMID: 29916205

Randomised controlled trials—the gold standard for effectiveness research

duardo Hariton, MD, MBA[1] and Joseph J. Locascio, PhD[2]

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Randomized Assignment of Treatment

When a program is assigned at random—that is, using a lottery—over a large eligible population, we can generate a robust estimate of the counterfactual. *Randomized assignment* of treatment is considered the gold standard of impact evaluation. It uses a random process, or chance, to decide who is granted access to the program and who is not.[1] Under randomized assignment, every eligible unit (for example, an individual, household, business,

RCTs are All the Rage

Massachusetts Institute of Technology (MIT)
@MIT

Professors Esther Duflo and Abhijit Banerjee, co-directors of MIT's @JPAL, receive congratulations on the big news this morning. They share in the #NobelPrize in economic sciences “for their experimental approach to alleviating global poverty.”

Photo: Bryce Vickmark

Vox (Oct 14, 2019)

But Not Everyone Agrees I

Angus Deaton

Economics Nobel 2015

> The RCT is a useful tool, but I think that is a mistake to put method ahead of substance. I have written papers using RCTs...[but] no RCT can ever legitimately claim to have established causality. My theme is that RCTs have no special status, they have no exemption from the problems of inference that econometricians have always wrestled with, and there is nothing that they, and only they, can accomplish.

Deaton, Angus, 2019, [“Randomization in the Tropics Revisited: A Theme and Eleven Variations”](), Working Paper

But Not Everyone Agrees II

Lant Pritchett

> “People keep saying that the recent Nobelists "studied global poverty." This is exactly wrong. They made a commitment to a method, not a subject, and their commitment to method prevented them from studying global poverty.”
>
> “At a conference at Brookings in 2008 Paul Romer (last years Nobelist) said: "You guys are like going to a doctor who says you have an allergy and you have cancer. With the skin rash we can divide you skin into areas and test variety of substances and identify with precision and some certainty the cause. Cancer we have some ideas how to treat it but there are a variety of approaches and since we cannot be sure and precise about which is best for you, we will ignore the cancer and not treat it.”

Source

But Not Everyone Agrees III

Angus Deaton

Economics Nobel 2015

> "Lant Pritchett is so fun to listen to, sometimes you could forget that he is completely full of shit."

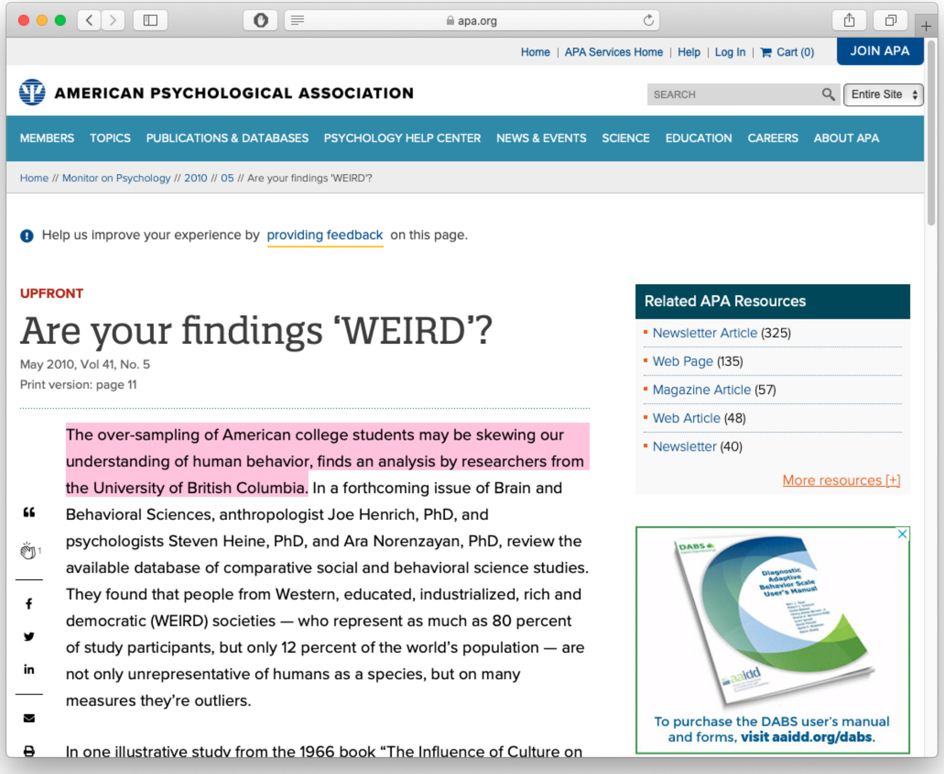
Source

RCTs and Evidence-Based Policy

- Programs *randomly* assign treatment to different individuals and measure causal effect of treatment
- **RAND Health Insurance Study**: randomly give people health insurance
- **Oregon Medicaid Expansion**: randomly give people Medicaid
- **HUD's Moving to Opportunity**: randomly give people moving vouchers
- **Tennessee STAR**: randomly assign students to large vs. small classes

RCTs and External Validity

- Even if a study is **internally valid** (used statistics correctly, etc.) we must still worry about **external validity**:
- Is the finding **generalizable** to the whole population?
- If we find something in India, does that extend to Bolivia? France?
- Subjects of studies & surveys are often **WEIRD**: **W**estern, **E**ducated, and from **I**ndustrialized **R**ich **D**emocracies



APA (2010)

RCTs and External Validity